Increased Bandwidth in Aloha-based Frequency Hopping Transmission Systems

BACKGROUND OF THE INVENTION

TECHNICAL FIELD

The invention relates to transmission systems. More particularly, the invention relates to a method and apparatus that provides increased bandwidth in Aloha-based frequency hopping transmission systems.

DESCRIPTION OF THE PRIOR ART

The installed base of cable television set-top boxes was designed for efficient downstream, *i.e.* cable plant to subscriber, information delivery. Upstream data transmission, *i.e.* from subscriber to cable plant, is much more restrictive, supporting only limited bandwidth. As new classes of interactive services become available, it becomes ever more important to increase the upstream transmission bandwidth. For example, if it is necessary to pass voice information from the subscriber to the cable headend (also known as the "headend"), sufficient upstream bandwidth must be made available.

One of the most popular digital set-top boxes, the General Instruments (now Motorola) DCT-2000, is a useful example. When the box was first deployed,

upstream transmissions were restricted to user pay-per-view requests, and other infrequent transmissions. As a consequence, the transmission format used for upstream transmissions was not required to be very efficient, and in fact, it is not very efficient.

In this set-top box, the transmit hardware is capable of selecting twenty different 256K bps channels, each of which uses QPSK transmission coding. While the hardware is capable of frequency-hopping to avoid channels which are subject to interference, the scheme used is fairly static, with typical deployments only using two active upstream communications channels, for an aggregate bandwidth of only 512K bps per cluster of set-top boxes. This cluster is called a node in cable television terms, and typically represents between 500 and 2000 subscribers.

Furthermore, the transmission control protocol used, referred to as Aloha, is one where an individual set-top box immediately transmits any pending request to the headend, without regard to whether or not the channel is already in use. This transmission is repeated at regular intervals until the box receives an acknowledgement command, indicating successful receipt of the transmission.

Downstream data transmission occurs in a separate frequency band from the upstream channels. As is well-understood, this transmission control protocol is quite inefficient due to the number of collisions which ensue, *e.g.* simultaneous transmissions from different set-top boxes which interfere with one another, forcing all of the transmitters to repeat their transmissions again. This leads to

typical channel utilization on the order of just 30%. As a consequence, the total bandwidth available for upstream transmission per node is only about 30% * 512K bps = ~137K bps, on average.

Transporting voice across this limited bandwidth is not practical because an individual voice stream requires a minimum of perhaps 4K bps, meaning that at most (137K / 4K =) 34 people could use the link simultaneously, which is as little as (34 / 2000 =) 1.7% of the available households.

It would be advantageous to provide a method and apparatus that increases bandwidth in Aloha-based frequency hopping transmission systems, for example, thereby allowing voice transmission in such systems.

SUMMARY OF THE INVENTION

The preferred embodiment of the invention provides a method and apparatus that increases bandwidth in Aloha-based frequency hopping transmission systems, for example, thereby allowing voice transmission in such systems.

A first step in improving efficiency of known systems is to increase the number of parallel upstream transmissions by changing known systems from frequency hopping to a parallel transmission model. To increase upstream bandwidth, the invention replaces the existing headend receiver with one that is capable of simultaneously receiving data from all of the possible upstream channels simultaneously.

Next, by treating the head-end receiver and the set-top boxes as an integrated system, it is possible to use the existing transmission spectrum much more efficiently. Instead of enabling each set-top box to perform frequency hopping, it is much more effective if the head-end receiver is made responsible for active frequency management of the upstream transmission spectrum. To do this, when the system is first powered-up, the head-end receiver examines the RF spectrum to determine which frequencies are available, and which are not available due to interference from other sources. After determining which frequencies are free of interference, the headend receiver then polls the node to determine how many set-top boxes are active in this node. Once this is complete, the headend receiver partitions the total number of set-top boxes into an approximately equal number of set-top boxes for each of the available upstream data channels. That is, the boxes are assigned a transmission channel. The head-end receiver then commands each set-top box to tune to the channel it has been assigned by sending the channel selection information to each set-top box, *i.e.* using the separate downstream transmission channel mentioned above.

A second major change to known systems revises the transmission control protocol from an Aloha system to a slotted assignment system. To do this, the head-end receiver is used not just to assign each set-top box a specific transmission channel, but also a specific transmission time slot. By assigning a specific set-top box to a particular slot, it becomes possible for multiple set-top

boxes to transmit in sequential slots, while assuring that the transmission packets do not collide.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a system architecture according to the invention;

Fig. 2 is a flow diagram showing a channel assignment scheme according to the invention;

Fig. 3 shows channel and status information and corresponding allocation table entries according to the invention;

Fig. 4 is a timing diagram showing slot assignments according to the invention; and

Fig. 5 shows is a flow diagram that the provision of high resolution slot interrupts in a low resolution device.

DETAILED DESCRIPTION OF THE INVENTION

The preferred embodiment of the invention provides a method and apparatus that increases bandwidth in Aloha-based frequency hopping transmission systems thereby allowing, for example, voice transmission in such systems.

Fig. 1 is a block diagram of a system architecture according to the invention. Such systems with which the invention may be used can include, but are not

limited to, a headend receiver 10 and one or more set-top boxes 11, 12 between which communication proceeds over a plurality of communications channels, *e.g.* Channel_1-Channel_N.

Hopping-Parallel Transmission

A first step in improving efficiency of known systems is to increase the number of parallel upstream transmissions. To do this, the nature of the transmission system must be revised. However, replacing existing set-top boxes is a very expensive proposition, so it is extremely desirable to devise a method of accomplishing this task using existing set-top boxes. The invention achieves this goal by changing such systems from frequency hopping to a parallel transmission model.

To increase upstream bandwidth, the first step is to replace the existing headend receiver with one that is capable of simultaneously receiving data from all of the possible upstream channels simultaneously, *i.e.* twenty in the case of the DTC-2000 discussed above.

Next, by treating the head-end receiver and the set-top boxes as an integrated system, it is possible to use the existing transmission spectrum much more efficiently. Fig. 2 is a flow diagram showing a channel assignment scheme according to the invention

Instead of enabling each set-top box to perform frequency hopping, it is much more effective if the head-end receiver is made responsible for active frequency management of the upstream transmission spectrum. To do this, when the system is first powered-up (100) and intermittently thereafter, the head-end receiver examines the RF spectrum to determine which frequencies are available (101), and which are not available due to interference from other sources. After determining which frequencies are free of interference, the headend receiver then polls the node to determine how many set-top boxes are active in this node (102). Once this is determined, the headend receiver partitions the set-top boxes into an approximately equal number of set-top boxes for each of the available upstream data channels (103). That is, the boxes are assigned a transmission channel. The head-end receiver then commands each set-top box to tune to the channel it has been assigned by sending the channel selection information to each set-top box (104), *i.e.* using the separate downstream transmission channel mentioned above.

The headend receiver uses an allocation table 14 (Figs. 1 and 3) to keep track of the assignments of channels by storing a mapping between each channel and the set-top box to which the channel is assigned. An important element of the allocation table is that it keeps track of areas which are deemed to be busy. Thus, a key function of a headend receiver is in finding those frequencies which are not available, and eliminating them from the allocation table.

One reason for using frequency hopping is that it is relatively insensitive to interference by virtue of the fact that if there is an interfering carrier, such carrier only interferes with one step of the frequency hopping sequence. Therefore, only a minimal amount of information is lost and an error correction scheme can usually correct for this loss.

In the preferred embodiment of the invention, if there is interference on a channel, *e.g.* the channel is busy, then the channel is removed from the allocation table and is not allocated to any set-top box until it is no longer busy. Thus, the invention actively avoids interference instead of passively correcting for or responding to such interference because busy channels are actually removed from the allocation table. When there is a need to assign a channel to a set-top box, the headend receiver only sees the available channels, as listed in the allocation table. When a busy channel becomes free, it is put back into the allocation table and can subsequently be assigned by the headend receiver.

By making this simple change, the number of upstream channels increases dramatically, from typically two upstream channels, to perhaps sixteen channels depending on the amount of interference which is actually present in the upstream transmission spectrum. In the case mentioned above, this provides eight times more upstream transmission bandwidth, allowing up to (1.7% * 8) = 13.6% of households to transmit voice information simultaneously.

Improving Channel Utilization

A second major change to known systems requires no hardware whatsoever, but revises the transmission control protocol from an Aloha system to a slotted assignment system. To do this, the head-end receiver is used not just to assign each set-top box a specific transmission channel, but also a specific transmission time slot (105; see Fig. 2).

For the purposes of this document, a "slot" (see Fig. 4) is a specific slice of time used to transmit information, typically a fraction of a second in length. Here, assume that each second on each channel is divided up into one thousand slots, for a slot length of one millisecond. By assigning a specific set-top box to a particular slot, which is stored in a time slot table 16 (see Fig. 1), it becomes possible for multiple set-top boxes to transmit in sequential slots, while assuring that the transmission packets do not collide.

It is known in time division multiple access systems which of many transmitters is allowed to transmit in a given time slot. One such method is referred to as a reservation protocol in which a talker who wants to talk requests, and is then assigned, one of the available time slots. When that time slot arrives, the talker talks, and then is quiet while others talk. The management and assignment of time slots comes from some central authority, which in the case of a cable modem system is the headend controller. A reserved time slot allows a modem to transmit a known amount of information in a known period. However, if the

modem does not wish to use the time slot, the time slot is not available for use by anyone else until the controller decides that the time slot is available and then assigns it to someone else. (see W. Ciciora, J. Farmer, D. Large, Modern Cable Television Technology, Ch. 4, pp. 199, Morgan Kaufman Publishers, Inc., San Francisco, (1999).

One general problem in known systems is that the assignment of slots normally requires very precise alignment of the timing of each device in the system, such that each transmitter knows precisely when its assigned slot time arrives.

One known technique is to define a guard band such that a worst case clock skew between different transmitters does not result in overlap from slot to slot. This guard band itself often requires a substantial protion of the bandwidth that is available. There are a number of factors that go into computing the optimal guard band, such as local oscillator inaccuracy multiplied by the duration of time between time synchronization, and uncertainty involved in the hardware transmission path, *i.e.* variation in latency between the various set top boxes for which it is difficult, if not impossible, to account.

The presently preferred method of assigning slots in the system herein is for the downstream data transmitter to broadcast a timestamp at a regular interval 106), *e.g.* every one second. This heartbeat is received by all set-top boxes in the network, forming a rigid timing standard for the boxes. By repeating the heartbeat at regular, *e.g.* one second, intervals the inherent timing inaccuracy of

the individual set-top boxes is not given the opportunity to become significant because each box resets its slot timers when it receives the broadcast time-stamp (114). In this manner, a consistent time is maintained throughout the network.

However, an additional problem arises in known cable systems. Because each of the set-top boxes may be at very different distances from the headend, and because each may have a different internal processing speed, the response time from the different set-top boxes is individually skewed, thereby preventing perfect alignment of the different transmission slots. To correct for this, the headend receiver requests that each individual set-top box echo a specific command (108) as rapidly as possible during system initialization (107), while polling the node for attached set-top boxes. At the instant the head-end receiver sends out the command, it begins running an internal timer (17; see Fig. 1). This timer is incremented (110) until a response is received from the set-top box (109). This response may be an echo of the timestamp. The value of the timer once the response has been received is an accurate measure of the propagation delay in the network, plus the processing delay in the particular set-top box. By applying this new knowledge, it becomes possible to align the timing for all set-top boxes in the system (111), so that the slot times are aligned.

Note that a timestamp is used to account for varying delays in downstream transmission. The timestamp which is transmitted contains a value indicating the actual moment in time when the transmitted packet hits the wire. By having the

set-top box echo the received timestamp, it becomes possible to measure the precise time overhead or loss inherent in the network and the particular set-top box, even in the presence of varying transmit delay in the downstream transmitter. Note that maximal accuracy may be obtained by repeating this process several times and averaging the time correction results.

To accomplish slot alignment, the head-end receiver transmits the time correction factor it computed while polling the set-top box back to the set-top box (112). Inside the set-top box, this timing correction factor is subtracted from the nominal slot time to find a corrected slot time (113). By doing so, the set-top box's processing time effectively becomes zero. As a consequence, by the time the set-top box actually begins transmission, its packet is aligned properly to the desired slot transmission point so that sequential transmissions do not interfere with one another.

As a final step, many set-top boxes do not have the hardware clock resolution to enable interrupts to occur at the desired slot frequency. To resolve this, a combination of interrupts and software counters are used to provide finer time granularity. Fig. 5 shows is a flow diagram that shows the provision of high resolution slot interrupts in a low resolution device. In essence, a hardware timer interrupt 17 (Fig. 1) is programmed to awaken the CPU at the set-top box at the nearest hardware interrupt point preceding the desired slot interval (150, 151), then software counters 18 are used to count down the remaining time (152) until this set-top box's transmission slot (153, 154). By combining these methods, it

becomes possible to have more slots available than the hardware interrupt would otherwise make possible because the slots may be subdivided into sub-slots that are finer than the resolution of the set-top box.

All told, this slotted approach to transmission can increase utilization of individual upstream channels from approximately 30%, to in excess of 80%. As a consequence, the number of simultaneous voice transmissions in the example system described here increases to (13.6% * 80% / 30%) = 36%, *i.e.* more than twenty times faster than the original installation. This substantial bandwidth increase is crucial because it enables entirely new classes of service to be delivered to subscriber's homes, without requiring expensive replacement of the installed base of set-top boxes.

Although the invention is described herein with reference to the preferred embodiment, one skilled in the art will readily appreciate that other applications may be substituted for those set forth herein without departing from the spirit and scope of the present invention. Accordingly, the invention should only be limited by the Claims included below.